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(54) Sensing rotation of a shaft electromagnetically

(57) A shaft (12), whose speed and sense of rotation is to be determined, is provided with encoding means, comprising two longitudinally displaced sets (22, 24), of magnetic "keys" which can be grooves, projections, insertions or flats, for example. A detector (14) comprises a primary coil for generating an alternating electromagnetic field, and two secondary coils for picking up the field and providing output signals. Rotation of the shaft moves the two sets of "keys" (22, 24) past the respective secondary coils, thereby modulating the amplitude of each of the alternating output signals in accordance with the speed of rotation of the shaft. The "keys" in the two sets (22, 24) are circumferentially offset so that the amplitude modulations of the two output signals are out of phase with one another, to permit determination of the sense of rotation. The shaft may be provided with an impeller (187), for determining the rate of flow of fluid in a conduit, e.g. a cased well bore-hole.

FIG.1D

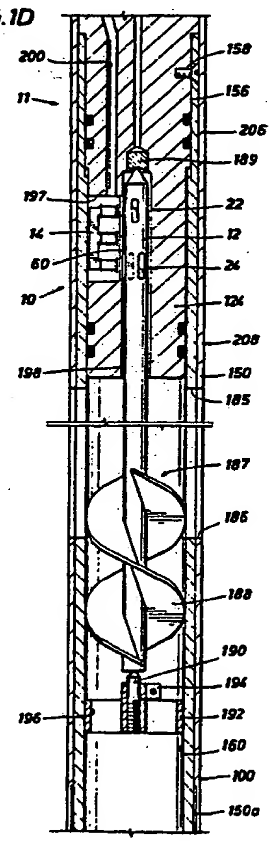

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FIG.1A

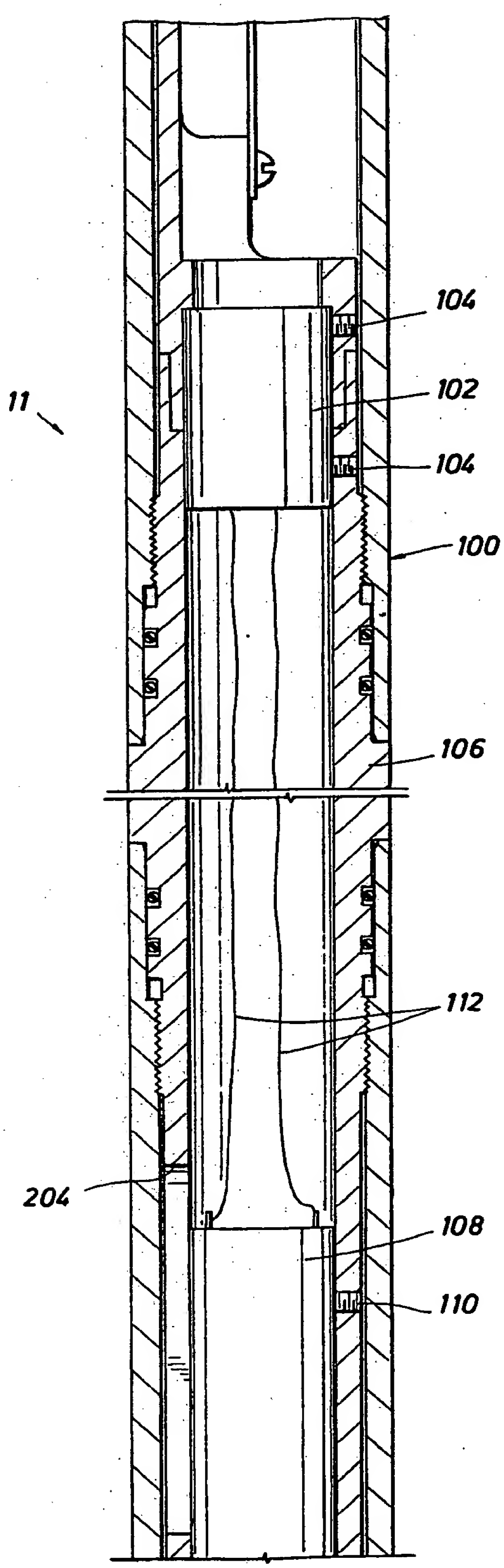


FIG.1B

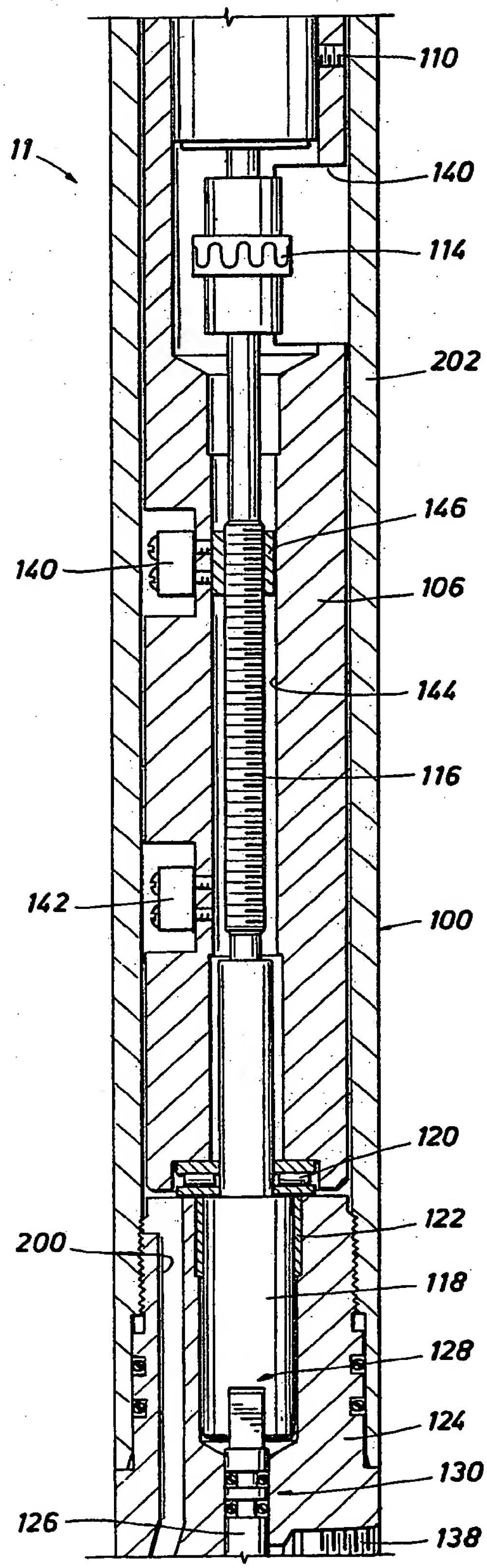
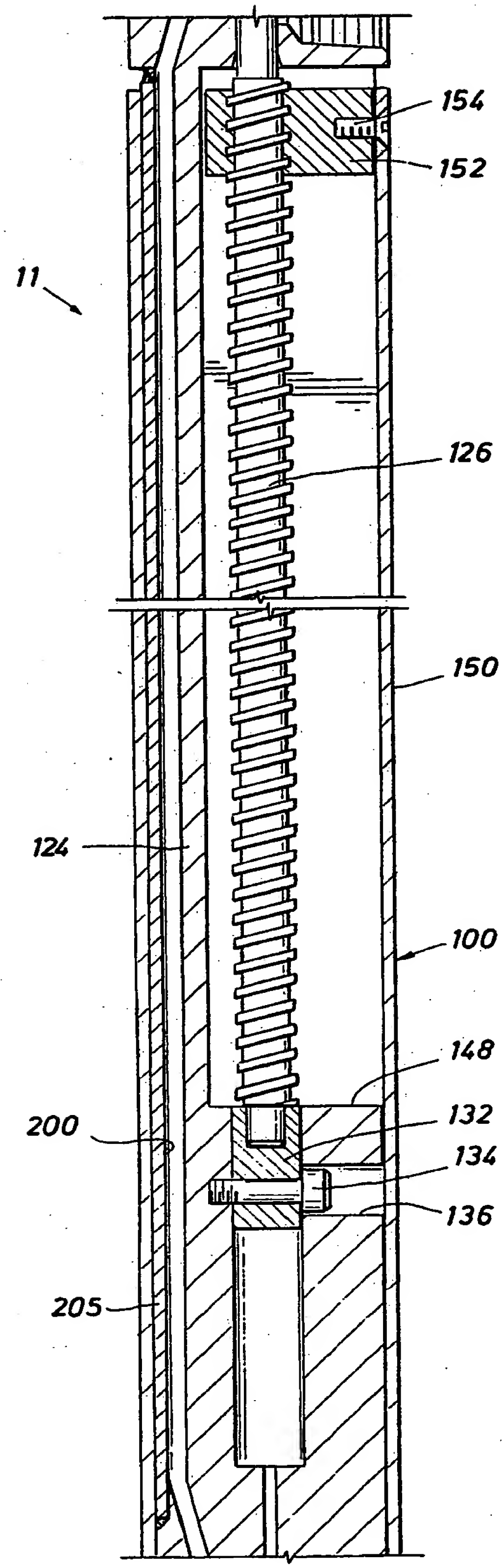
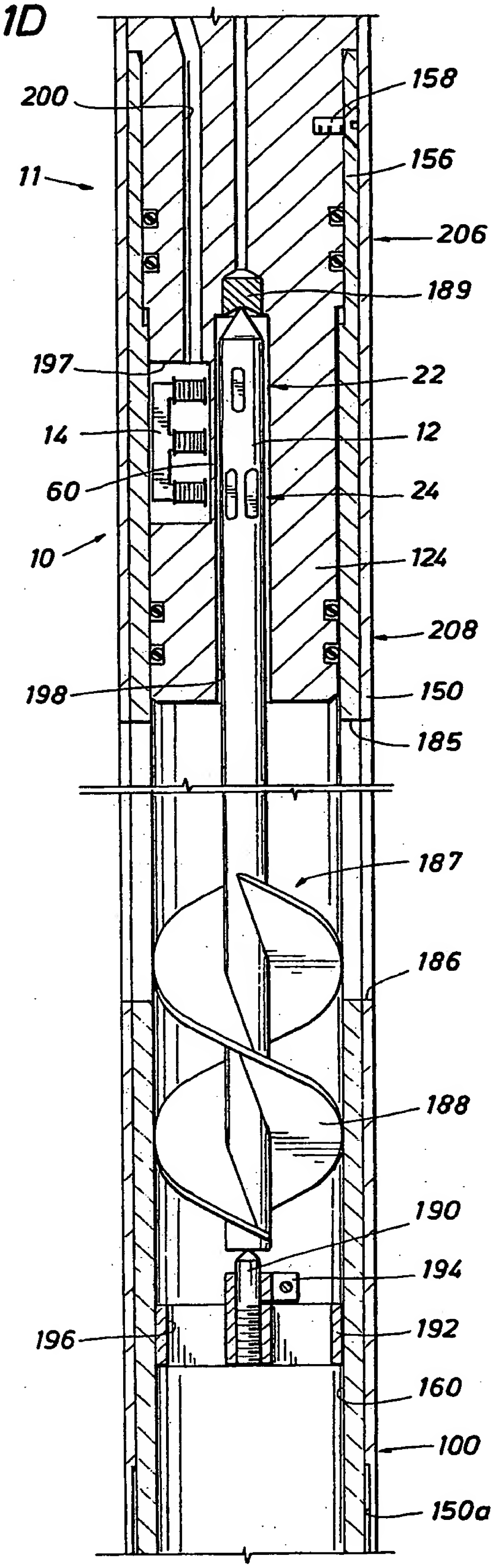


FIG.1C



154
152
11
126
150
124
100
148
200
132
134
136
205

FIG.1D



200
158
156
11
206
189
197
22
14
12
60
24
10
124
208
198
150
185
187
186
188
190
194
196
192
160
100
150a

FIG.1E

FIG.7

FIG.8

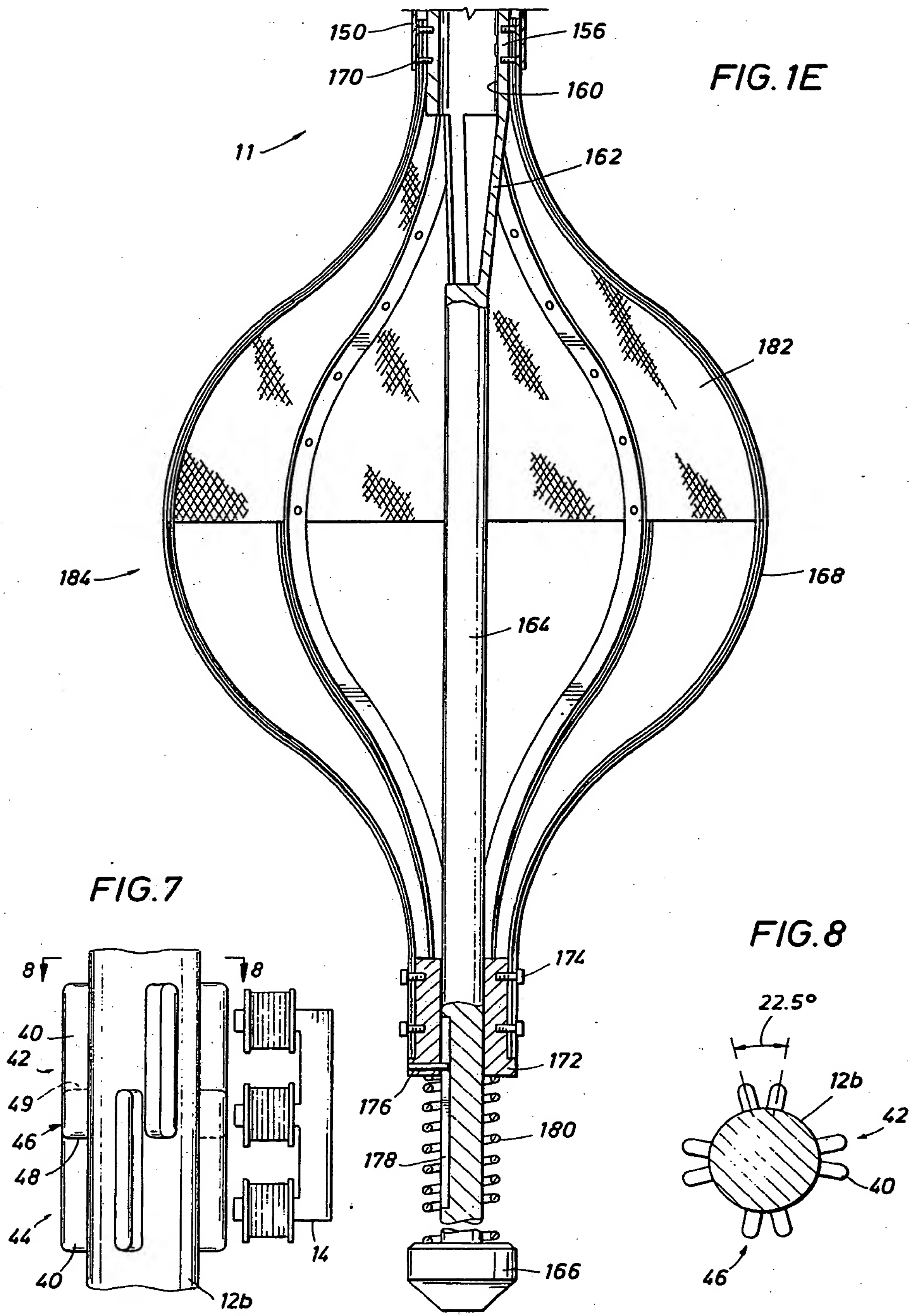


FIG.2

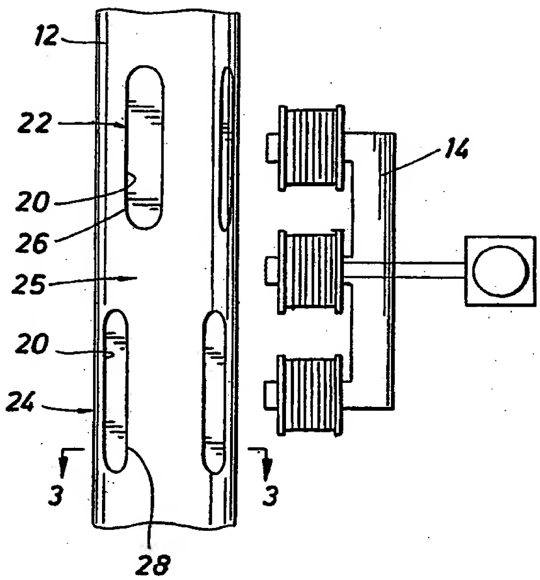


FIG.4

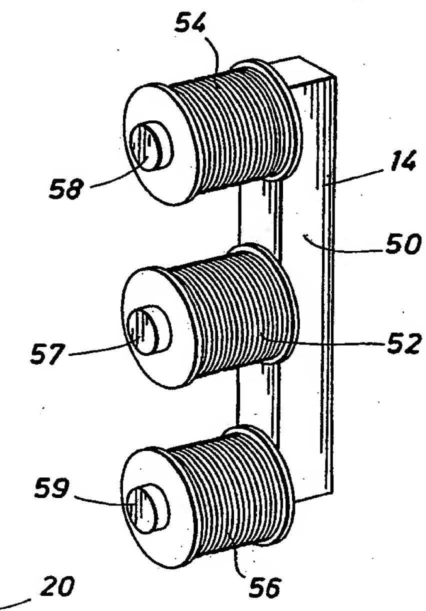


FIG.3

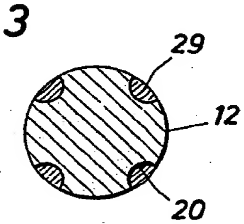
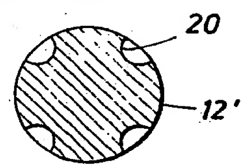


FIG.3A



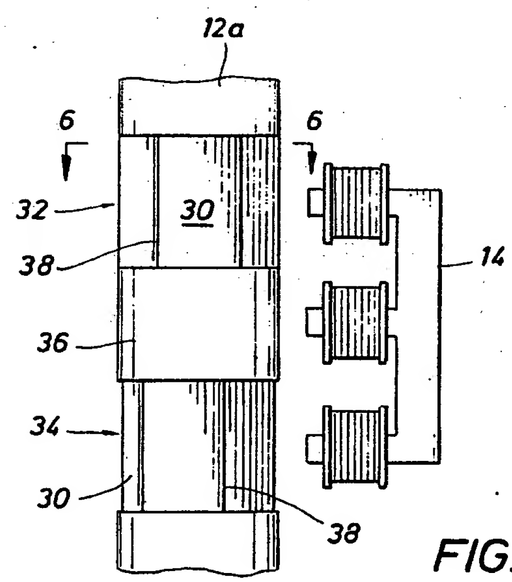


FIG.5

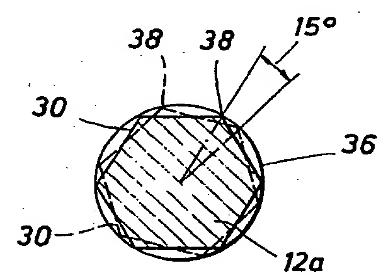


FIG.6

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FIG. 9

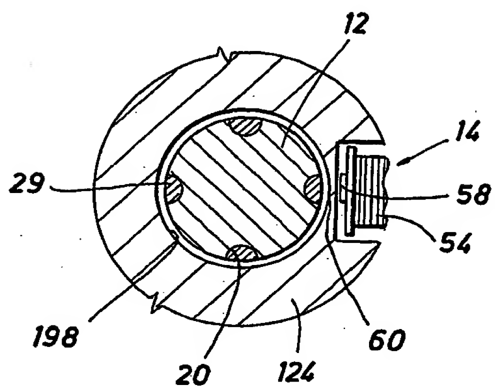


FIG. 10

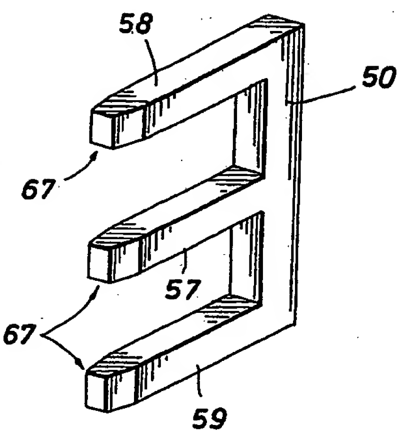


FIG. 13

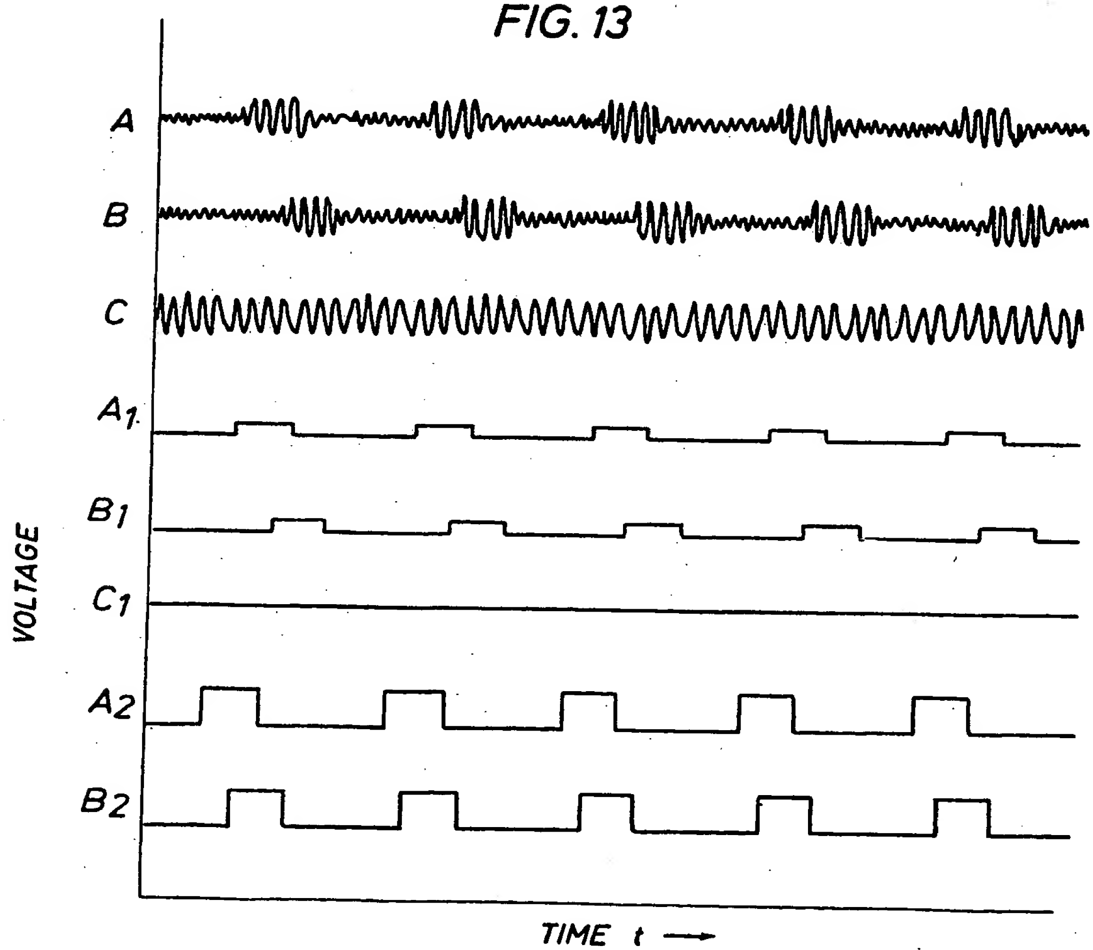


FIG.11

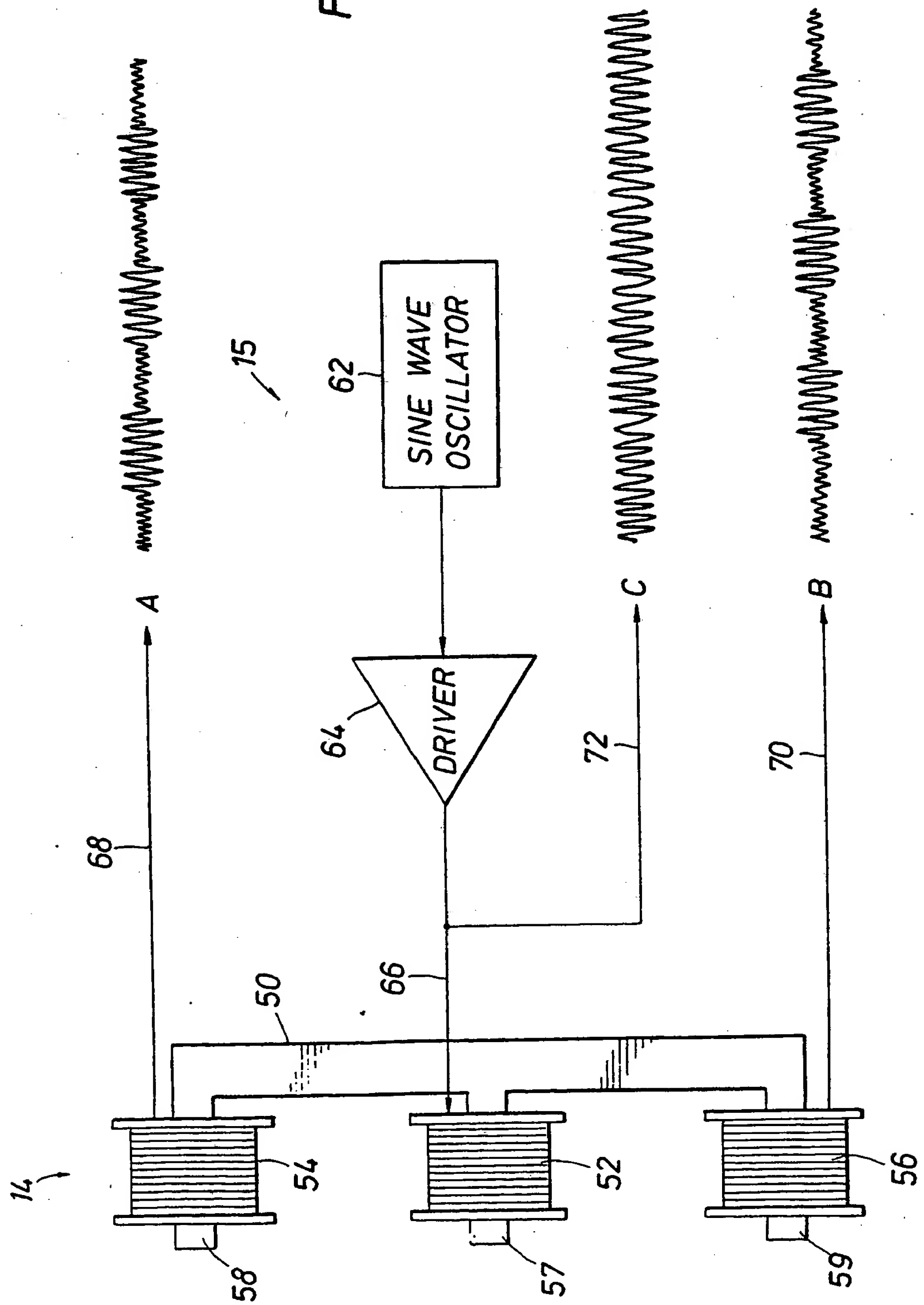
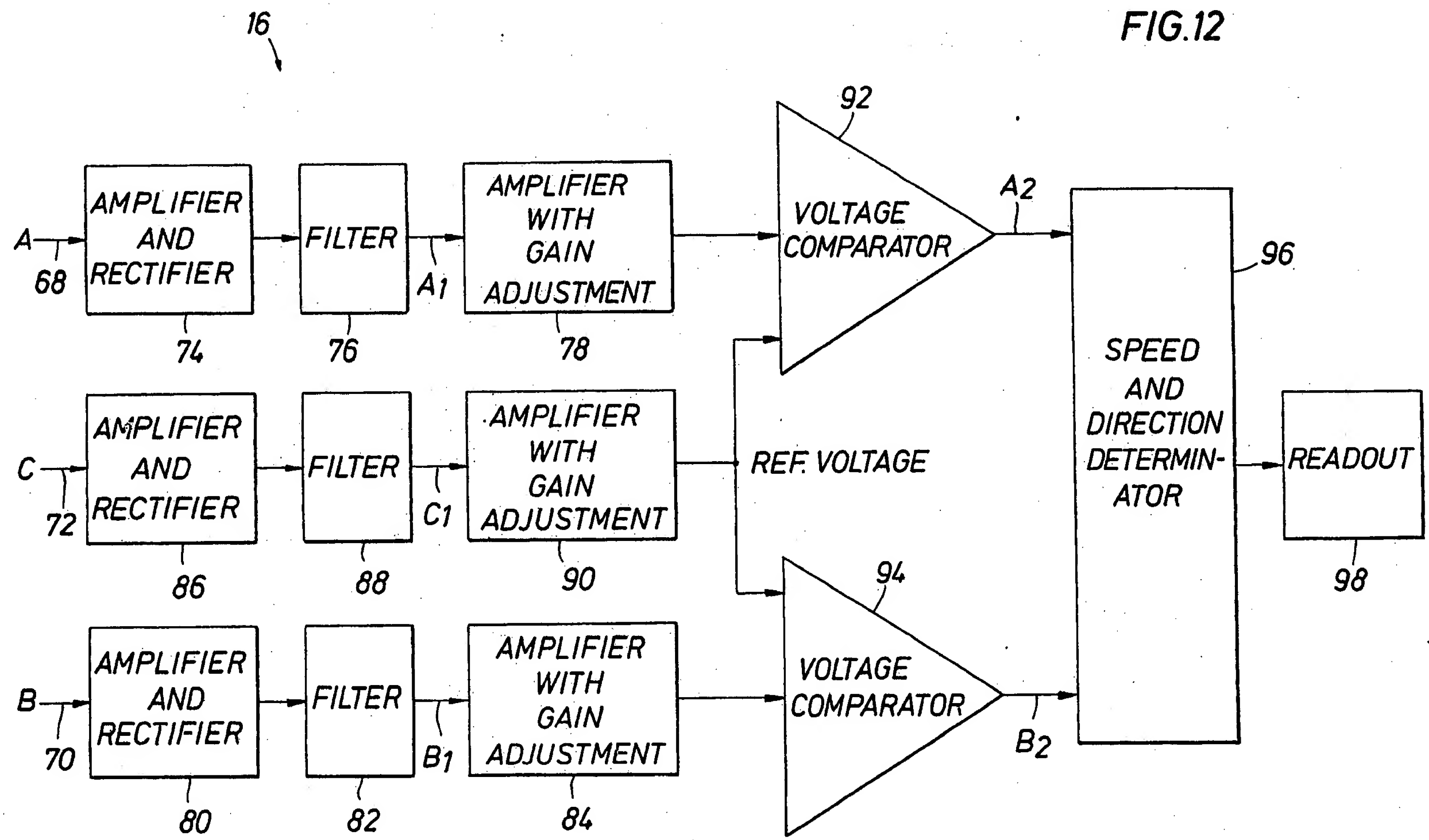

SINE WAVE OSCILLATOR
62
DRIVER
64
15
A
C
B
68
72
70
66
50
54
52
56
58
57
59
14

FIG.12


16
A
68
AMPLIFIER AND RECTIFIER
74
FILTER
76
A1
AMPLIFIER WITH GAIN ADJUSTMENT
78
C
72
AMPLIFIER AND RECTIFIER
86
FILTER
88
C1
AMPLIFIER WITH GAIN ADJUSTMENT
90
B
70
AMPLIFIER AND RECTIFIER
80
FILTER
82
B1
AMPLIFIER WITH GAIN ADJUSTMENT
84
92
VOLTAGE COMPARATOR
A2
REF. VOLTAGE
94
VOLTAGE COMPARATOR
B2
SPEED AND DIRECTION DETERMIN-ATOR
96
READOUT
98

SPECIFICATION

Apparatus f r s nsing m ti n f a b dy

This inv ntion relates to apparatus for sensing motion of a body, for example for determining the speed of rotation of a shaft. This invention finds particular application in the determination of direction and rate of fluid flow in wells, such as oil and gas wells.

Methods currently utilised for measuring the speed and/or direction of rotation of bodies are embodied in both mechanical and electrical devices.

Common techniques of measurement of shaft rotation through mechanical methods include attaching a universal gear to the shaft and connecting various gearing arrangements to that universal gear to operate an indicator. Similarly, mechanical tripping counters can be used to count the number of revolutions per preset period of time. Inherent in such prior mechanical devices are problems that affect the accuracy of measurement. Such devices produce drag upon the shaft. This can slow the speed of rotation or waste energy overcoming that drag. Secondly, such mechanical devices cannot be isolated from the object of their measurement, leaving such devices possibly susceptible to corrosion and mechanical failure. Finally, these mechanical devices can be costly to manufacture and difficult to assemble.

An alternative to mechanical measuring devices is provided by electrical measurement of rotation using magnetic proximity detectors or phase shift coils, for example. Such apparatus does not, however, detect the sense of rotation of a body.

A magnetic proximity detector employs a dc-operated electromagnet whose field flux is altered by variations in the structure of a shaft rotating adjacent the magnet. In the case of slowly rotating shafts, the low flux change rate is difficult to read. Further, the dc-type magnetic field imposes a drag on the shaft that may significantly alter the rate of rotation of the shaft in an otherwise relatively friction-free environment.

A phase shift coil detector depends upon the inductance of its coils, and compares a reference signal with a signal phase-shifted by the effects of a rotating body adjacent one of the coils. Information obtained using a phase-change technique can be unreliable at relatively high temperatures where the coil inductance may be altered.

It is desirabl to provid low cost, accurat and drag-free apparatus for measuring both speed and sense of rotation of bodies. In many settings, a high temperature rating, a linear output to zero rotation rate, and resistance to the effects of vibration are important. An object of the present invention is to make it possible to achi ve these advantages.

According to the present invention there is provided an apparatus for sensing motion of a body, said apparatus comprising:

a detector including a primary coil for generating an electromagnetic field signal and a secondary coil positioned to pick up said signal and provide an output signal representative thereof;

encoding means, including magnetic material, associated with said body for movement therewith; and

said detector being disposed adjacent said body so that movement of the body moves the encoding means relative to the detector to vary the degree of flux linkage provided by said magnetic material between the primary coil and the secondary coil, whereby to vary the magnitude of said output signal in response to said motion.

In another aspect the invention provides an apparatus for sensing the rotary motion of a shaft, said apparatus comprising:

a detector including a primary coil for generating an alternating electromagnetic field signal and a secondary coil positioned to pick up said signal and provide an alternative output signal representative thereof;

encoding means, including magnetic material associated with said shaft for rotation therewith;

said detector being disposed adjacent said shaft so that rotation of the shaft rotates the encoding means relative to the detector to vary the degree of flux linkage provided by said magnetic material between the primary coil and the secondary coil, whereby to modulate the amplitude of said alternating output signal in accordance with the speed of rotation of the shaft.

The magnetic encoding may be provided, at least in part, by material of relatively high permeability to provide zones of relatively high magnetic effect, that is, zones capable of effecting relatively large flux linkages, and by material of relatively low permeability to provide zones of relatively low magnetic effect, that is, zones capable of effecting generally lesser or no flux linkage. The magnetic encoding means may also be provided, at least in part, by the configuration of the magnetic material of the encoding whereby movement of the encoding means relative to the detector effects variation in the relative displacement between the magnetic material and the detector so that relatively small displacement provide zones of relatively high magnetic effect, and r latively large displacements provide zones of relatively low magnetic effect. A combination of materials of differing permeability and such materials arranged to vary the displacements of same relative to the detector may be utilised to provide the magnetic encoding.

The magnetic encoding may be provided on a shaft whose rotation is to be measured, as

in a spinner transducer. The shaft may be constructed of generally non-magnetic, or low permeability material, for example, with a pattern of longitudinally-ext nding deposits, such as strips, of magnetic, or high permeability material arranged in circumferential array about the shaft. Such strips may be formed, for example, by positioning magnetic material inserted within grooves cut into the shaft, or by attaching projections of magnetic material along the shaft. In the latter case, the shaft proper may be either of magnetic or non-magnetic material, and the projections may be either solid magnetic material, or coated with magnetic material. Another method of providing the magnetic coating is to construct at least a portion of the shaft with flat surfaces separated by longitudinally-extending edges. The shaft may then be solid magnetic material, or constructed of non-magnetic material with the edges being magnetic. A shaft made of magnetic material may be provided with a pattern of grooves so that the displacement of magnetic material of the shaft relative to the detector varies as the shaft rotates.

Since the present invention employs alternating electronic signals to produce alternating magnetic fields whose amplitude modulation is utilised to obtain the desired motion information, such motion information is impervious to, for example, frequency drift of the carrier signal, or vibration of the rotating shaft in such application. The output signals may be processed to obtain pulsed dc signals, which may be readily analyzed by the counting of the pulses and the notation of the relative phase shift between the two pulse signals from the two pick up coils. The use of alternating magnetic fields in the detector results in virtually no drag due to magnetic field linkage between the moving body, such as a rotating shaft, and the detector. Further, since the detection technique relies on amplitude modulation, which may be enhanced lectronically if necessary, the detector may be non-magnetically isolated from the moving body, particularly where such body may be subjected to an environment which could be corrosive or otherwise detrimental to the detector. The core of the detector may be made of a single, solid piece of ferrite material, rendering a high and flat inductance up to a significantly high temperature.

In a particular embodiment illustrated, a spinner transducer tool according to the present invention is incorporated in a flow measuring device which finds particular application in determining rate of flow of fluids along wells. The encoding portion of the spinner transducer tool is included on the shaft of an impeller which is caused to rotate by fluid flowing through the flow measuring device, The detector portion of the spinner transducer tool, as well as the electronic circuitry needed t power th detector and to analyse the output signals from the pickup coils, are fluid-isolated from the magnetically keyed shaft.

Embodiments of the invention will now be described by way of example, with reference to the accompanying drawings, in which:—

Figure 1 is an elevation in partial section of a fluid flow measuring device incorporating a spinner transducer tool according to the present invention, and includes Figs. 1A, 1B, 1C, 1D and 1E illustrating sections of the measuring device in sequence from top to bottom, respectively, with the scale of Fig. 1E reduced;

Figure 2 is an elevation, partly schematic, of a portion of one version of the spinner transducer tool, particularly illustrating the alignment of the detector mechanism in relation to a groove-encoded shaft;

Figure 3 is a cross-sectional view of the shaft taken along line 3–3 of Fig. 2, showing an embodiment of the invention having non-magnetic shaft material and grooves containing magnetic material;

Figure 3A is a view, similar to Fig. 3, of the shaft showing an embodiment of the invention having magnetic shaft material and open grooves, or grooves containing non-magnetic material (not shown);

Figure 4 is a perspective view of the detector mechanism;

Figure 5 is an elevation of a portion of another embodiment of the spinner transducer tool, particularly illustrating the alignment of the detector mechanism in relation to a flat-encoded shaft;

Figure 6 is a cross-sectional view of the shaft with flats taken along line 6–6 of Fig. 5;

Figure 7 is an elevation of a portion of another embodiment of the spinner transducer tool, particularly illustrating the alignment of the detector mechanism in relation to a projection-encoded shaft;

Figure 8 is a cross-sectional view of the shaft with projections taken along line 8–8 of Fig. 7;

Figure 9 is a fragmentary cross-sectional view of the groove-encoded shaft of Fig. 2, further illustrating a thin wall barrier between the shaft and the detector mechanism;

Figure 10 is a perspective view of the detector mechanism core with beveled pole faces for flux focusing;

Figure 11 is a block diagram of electronic exciter circuitry for providing the input electronic signals to the detector mechanism;

Figure 12 is a block diagram of electronic data reduction circuitry for interpreting the output signals from the detector mechanism; and

Figure 13 is a timing diagram for comparing the output signals from the two pickup coils, both before and after the signals are processed.

A spinn r transducer tool in accordance with present inv ntion is shown in part gen r-

ally at 10 in Fig. 1D in operating position within a fluid flow measuring device which is illustrated generally at 11 in Figs. 1A–1E. The spinner transducer tool 10 is shown in detail in part in Figs. 2, 3 and 4. The spinner transducer tool 10 generally includes four major components: a generally cylindrical shaft segment 12, a detector or sensor mechanism 14, the exciter circuit, shown schematically at 15 in Fig. 11, and a pulse-counting circuit, which is shown schematically at 16 in Figure 12. In mutual cooperation, these elements may serve to determine the speed and direction of rotation of the shaft 12 and equipment attached thereto.

The shaft 12 is rotatably mounted within the fluid flow measurement device 11 as described more fully hereinafter, and is magnetically encoded to provide rotation information to the detector mechanism 14. The encoding may be achieved in a variety of ways.

As maybe appreciated by reference to Fig. 2, the shaft 12 has one or more grooves 20 located in each of two axially spaced sets shown generally at 22 and 24 on the shaft. The groove sets 22 and 24 are separated by a shaft region shown generally at 25. The grooves 20 may be formed by milling, casting, or any other appropriate method. Each set 22 and 24 has four grooves 20 spaced at equidistant locations along the circumference of the shaft 12, as illustrated in Fig. 3. The number of grooves 20 is not critical to the invention, but both groove sets 22 and 24 preferably include the same number of grooves, and such will be considered hereinafter. It is preferably that all grooves 20 be the same shape and size. Further, the grooves of one set 22 are circumferentially displaced, or offset, from the grooves of the other set 24 as shown. The offset may be measured from the centers of the grooves 20, or in any other convenient manner. These various features of the grooves 20 are dictated, in part, by the diameter of the shaft 12.

The circumferential displacement, or offset, between the grooves 20 of the two sets 22 and 24 is generally equal to one fourth of the circumferential displacement between consecutive grooves in each set. As described more fully hereinafter, the passage of each groove 20 by the sensor 14 during rotation of the shaft 12 is accompanied by the generation of an electronic pulse, with each set of grooves 22 and 24 thus providing a separate electronic signal comprising a stream of pulses. If the shaft rotation rate is constant, the signal pulse rates are constant with the grooves 20 equally-spac d about the shaft 12 in each set 22 and 24. For each signal, the period defined by consecutive pulses is equal to the time b tw en passage of cons cutive grooves 20 in th corresponding gro ve set 22 or 24 by the sensor 14. This time and, hence, the circumferential distance between consecutive grooves 20 in a set 22 or 24, may be described as a 360° phase. Thus, a 90° phase delay or shift in the elctronic signal generated by a groove set 22 or 24 corresponds to one quarter of the distance along the circumference between consecutiv grooves in the set of grooves. Then, with the grooves of one set 22 or 24 circumferentially offset from the grooves in the other set by one quarter the circumferential distance between consecutive grooves in each set, the electronic signals of pulses produced by the two groove sets passing by the sensor 14 will be 90° out-of-phase, with one signal leading or lagging the other, depending on the relative orientations of the two groove sets (which one "leads" the other on the rotating shaft 12) and on the direction of rotation of the shaft, as discussed more fully hereinafter.

The number of grooves 20 within each set 22 and 24 will be determinative of the circumferential offset distance to achieve the 90° phase difference between the electronic signals. For example, if there is only on groove 20 per set, then the groove in set 22 must be offset one quarter of the circumference of the shaft 12 from the groove in set 24, or along an arc subtended by a 90° central angle of the cylindrical shaft. Howev r, if there are four grooves 20 within each set as illustrated, then the grooves in set 22 must be offset from the grooves in set 24 through a 22.5° central angle. Generally, the grooves are wide enough so that there is an overlap in time of pulses generated by corresponding, 90°-shifted grooves of the two sets. For example, as viewed in Fig. 2, the left edge 26 of a groove 20 within the upper set 22 is preferably farther to the left than the right edge 28 of the corresponding groove within the lower set 24 to achieve the desired signal pulse overlap. This pulse overlap is utilised for a determination of rotation direction, as explained below. The depth and length of each of the grooves 20 is dependent upon the size and sophistication of the detection mechanism and the pulse counting equipment, as also discussed further hereinafter.

The shaft 12 is encoded with magnetic material. One technique, as shown in Fig. 3, is to provide the grooves 20 in a shaft made of non-magnetic material. Magnetic filler material 29 is used to fill each of the grooves 20. An alternative, as shown in Fig. 3A, is to make the shaft 12′ of magnetic material and retain the grooves 20 empty. In such case, however, the grooves 20 may be filled with non-magnetic material (not shown), such as epoxy, to maintain shaft balance for high speed rotation, and to provide a smooth, continuous surface for non-turbulant fluid flow in a fluid flow measuring device such as 11 as shown. Regardless of the manner of encoding, the changes in the magnetic properties of the shaft passing adjacent the sensor 14

cause generation of the puls signals. Thus, the sensor 14 "sees" the non-magnetic shaft 12 of Fig. 3 for relatively long periods separated by relatively short periods with the magnetic material 29 in the grooves 20 adjacent the sensor, wherein the pulses are generated. Alternatively, the sensor 14 "sees" the magnetic shaft 12' of Fig. 3A for relatively long periods broken by relatively short periods with the grooves 20, either hollow or containing non-magnetic material, adjacent the sensor, wherein "negative pulses", or amplitude reductions, are effected. In either case, the variation in relative position of magnetic material with respect to the sensor 14 affects the sensor and related circuitry (Fig. 12) to produce the pulsed signals.

In Figs. 5 and 6, another embodiment of the spinner transducer tool is indicated. A shaft 12a in this embodiment has flats 30 formed about the circumference of the shaft in two axially spaced sets, shown generally at 32 and 34, separated by a cylinderical portion 36. It is preferable that each flat area 30 within each set 32 and 34 is of the same length and width as those of every other flat within the set, and that the flats in a set occupy the entire circumference of the shaft 12a defining longitudinally extending edges 38 positioned equidistant about the shaft circumference. While Figs. 5 and 6 show six flat areas 30 within a set, the number of flats is not critical to the invention. More or fewer flats may be incorporated depending on the capability of the detection mechanism or on the need for accuracy of measurement. However, it is preferable that both sets of flats 32 and 34 be of identical form, that is, include the same number of flats 30, will all flats being of the same configuration.

As in the case of the embodiments of Figs. 2–3A, the sets of flats 32 and 34 are mutually circumferentially offset as indicated in Fig. 6. Again the degree of the circumferential offset is generally one quarter the circumferential distance between consecutive edges 38 in one set 32 and 34 to achieve a 90° phase shift, both structurally as illustrated, and in the electronic signals produced by rotation of the two sets 32 and 34 by the sensor 14 as discussed more fully hereinafter. In the case of six flats 30 in each set 32 and 34, each edge 38 in one set is offset by a central angle of 15° from a corresponding edge in the other set as indicated in Fig. 6.

The embodiment of Figs. 5 and 6 requires that the shaft 12a, or the surface of the shaft, or at least the dges 38, be mad of a magnetic material. Then, the variation of distance between the sensor 14 and the magnetic material carried by the shaft 12a in any such configuration, as the shaft rotates, affects the magnetic sensor to cause the pulse signal generation by tending to alternatively open and close flux links in the sensor.

A fourth mbodiment of th present invention is indicated in Figs. 7 and 8. A shaft 12b has longitudinally-extending projections 40 arranged about the circumference of the shaft. The projections 40 may be attached to the shaft 12b by soldering, welding, or any other rigid mounting method, or may be integral with the shaft. The projections 40 occur in two sets shown generally at 42 and 44. Preferably, in each set 42 and 44 all the projections are of the same size and shape, and are arrayed equidistant about the circumference of the shaft 12b. The number of projections 40 in each set 42 and 44 is not critical to the invention, and may be as low as 1, but it is preferred that both sets have the same number, construction and configuration of projections.

The two sets 42 and 44 of projections are generally mutually axially displaced, but overlap longitudinally in a middle area shown generally at 46 with the bottom ends 48 of projections in the upper set 42 extending below the top ends 49 of projections with th lower set 44. The two sets of projections are mutually circumferentially offset by a quarter of the circumferntial distance between consecutive projections 40 in either set to achieve the spatial and electronic 90° phase difference as described herein. With four projections 40 in a set, the circumferential offset subtends a central angle of 22.5° as indicated in Fig. 8.

The projections 40 are constructed of, or are at least covered with, magnetic material, and may be formed on a shaft 12b made of either magnetic or non-magnetic material. The region about the circumference of the shaft 12b and between consecutive projections 40 of each set 42 and 44 may be filled with non-magnetic material (not shown) to provide a smooth, cylindrical shape to ensure shaft balance and/or non-turbulent fluid flow along the shaft, as discussed before relative to the embodiment of Fig. 3A. As in the previously-described cases, the variation in distance between the sensor 14 and the magnetic material of the shaft 12b as the latter rotates near the sensor affects the sensor to produce pulsed electrical signals, whether the shaft proper is magnetic or non-magnetic.

The encoded shaft segment of the transducer 10 is not limited to the above-described embodiments, but may employ any configuration of magnetic coding which varies the displacement of one or more concentrations of magnetic material, carried by the shaft, relative to the sensor 14 as the shaft is rotated relative to the sensor. To enhance the ability of apparatus according to the invention to determine rotational speed, the configuration of magnetic material causing such variation in displacement should occur at uniform intervals about the circumference of the shaft. If sp ed information is required, but not directional information, then the shaft may have

only one set of grooves, flats or projections, rather than two.

The detection mechanism 14 acts as a sensor for detecting the flats (edges), grooves (fill), or projections of the magnetic coding. The detector 14 includes three major components: a core 50, an exciter coil 52, and two pickup coils 54 and 56 on opposite sides of the exciter coil (see Fig. 4). The detector 14 senses variations in distance between the pickup coils 54 and 56, in combination with the exciter coil 52, and the magnetic coding material on the shaft encoded segments.

The core 50 is in the form of an "E" with a center leg 57 and end legs 58 and 59 and is preferably made of a single, solid piece of ferrite material. The coils 52, 54 and 56 are positioned on the legs 57, 58 and 59, respectively, as shown in Fig. 4. Such a core 50 features a high and flat inductance up to 235°C. This feature is particularly advantageous in oil well drilling and exploration activities where downhole temperatures will frequently rise to this level. Furthermore, even when the temperature rises above 235°C and the core 50 starts to lose its inductance, the inductance within the single-piece, ferrite core will return to normal upon the lowering of the temperature. Thus, the single-piece ferrite core 50 is preferable to a laminated core, for example.

As illustrated in Figs. 1D, 2, 5 and 7, the detector 14 is positioned generally parallel to the shaft 12 (12', 12a or 12b), with the exciter coil 52 and leg 57 aligned with the shaft region 25 or 36 between encoding sets 22 and 24, or 32 and 34, respectively, or with the projection overlap area 46 of the projection sets 42 and 44. The pickup coils 54 and 56, on legs 58 and 59, respectively, are aligned with the upper and the lower encoding sets respectively (22 and 24; 32 and 34; or 42 and 44). The exact configuration of the detector 14 relative to the shaft (in any form) is not critical to the proper functioning of the present invention, and may be varied. However, in general, the distance between the shaft and the detector 14 may affect the strength of data signals ultimately produced in the pickup coils 54 and 56 with greater signal strength achieved by reduction of the distance.

The effect of the rotating coded shaft on the sensor 14 in causing the generation of pulse signals is, in general, increased as the lateral distance between the shaft and the sensor is decreased. But this distance may be kept sufficiently large to allow a thin wall 60 of non-magnetic material to mechanically isolate the shaft from the sensor, as shown in Fig. 9 and as disussed more fully below.

The "E" core 50 may be considered as including two "C" cores, each comprising the central leg 57 carrying the exciter coil 52, and one or the other of the end legs 58 or 59, with the corresponding pick up coil 54 or 56, respectively. The exciter circuitry 15 (Fig. 11) includes an ac, or sine wave, generator 62 which provides an output ac signal with a frequency in the range of 10–100 kHz, for example, though the specific frequency is n t critical to the invention. The sine wave signal is enhanced by a driver 64, providing signal C, for transmission along appropriate conductors 66 to the exciter coil 52. The changing electromagnetic field associated with the ac signal C thus impressed on the exciter coil 52 produces alternating magnetic fields in the "E" core 50, and through each end leg 58 and 59, and the respective pickup coil 54 and 56. In each case, the magnetic material carried by the rotating shaft tends to act as a shunt to close the magnetic flux path across the respective "C" core, thus increasing the magnetic linkage between the exciter coil 52 and the pickup coil in question. The flux path in each case is opened again as the shaft rotates, lessening the magnetic flux, generated by the exciter coil 52, that links the corresponding pickup coil.

The legs 57–59 of the "E" core 50 may be bevelled, or otherwise shaped, at the pole faces formed by the ends thereof as shown at 67 in Fig. 10 to concentrate the magnetic flux at the faces. With the flux thus focused, the variation in flux linkage as the magnetic coding of the shaft passes by the sensor 14 with the shaft rotation may be more pronounced, yielding greater signal modulation produced by the sensor. Where the construction of the shaft is that the magnetic coding is more distinct, as in the case of the grooves 20 filled with magnetic material 29 (Figs. 2 and 3) for example, such focusing by pole face shaping is not essential. For less radical coding, as in the case of the shaft 12' of magnetic material with grooves 20 containing no magnetic material, the variation in flux linkage with shaft rotation may be suitably enhanced by focused-field pole faces as shown in Fig. 10.

The ac signal C impressed on the exciter coil 52 will always be received by each of the pickup coild 54 and 56, but the amount, or amplitude, of signal received by each pickup coil is increased when the flux linkage is "closed" by the positioning of magnetic material carried by the shaft adjacent the opening in the respective "C" form of the core 50, the signal received by the pickup coil in question decreasing in amplitude as the magnetic material is rotated away to "open" the flux linkage across the "C". Th number of turns and the wire size included in the exciter coil 52 affect its inductive reactance, and, therefore, the strength of the signal available at the core 50. The number of turns in each pickup coil 54 and 56 determines, in part, the signal level receivable by these coils for modulation by the magnetic coding of the shaft. In both cases, the signal response of the sensor

14 is increased with an incrrease in coil windings. Typically, a well responsive transduc r may be provided according to the present invention, with a solid ferrite core 50, generally with 200 windings in each coil 52–56, in contrast to the approximately 1,000 windings that might be required in conjunction with a laminated core.

Since the signal generated by the oscillator 62 and impressed on the exciter coil 52 is, in general an alternating current sine wave the resulting magnetic flux signal linking the exciter coil with the two pickup coils 54 and 56 is also an alternating signal, with the magnetic field periodically changing direction at a relatively rapid rate. Consequently, the magnetically-encoded rotating shaft 12 experiences little or no magnetic drag, as opposed to the magnetic drag which may be exerted on a rotating shaft in the case of magnetic proximity or phase shift detectors which utilize constant magnetic fields.

In operation, the shaft may generally rotate in either a clockwise or a counterclockwise direction. As noted hereinbefore, as the shaft rotates adjacent the sensor 14, magnetic material carried by the shaft passes by each of the pickup coils 54 and 56, tending to close, or shunt, a loop in the core 50 including the xciter coil 52 and the respective pickup coil. When either core loop is thus shunted, the sinusoidal signal generated in the respective pickup coil 54 or 56 increases in amplitude. As the shaft continues to rotate, and the linkage between the pickup coil in question and the exciter coil 52 is again opened by the removal of magnetic coding material from the immediate vicinity of the sensor 14, the amplitude of the signal induced in the respective pickup coil is reduced accordingly. Thus, in the case of the non-magnetic shaft 12 with two sets 22 and 24 of grooves 20 filled with magnetic material 29 (Figs. 2 and 3), it is the passage of the magnetic filler material 29 adjacent the sensor 14 which shunts the core 50 to increase the amplitude of the signal induced in the corresponding pickup coil. In the case of the shaft 12′ constructed of magnetic material, and carrying grooves 20 that are either empty or filled with non-magnetic material (Fig. 3A), the proximity of the cylindrical surface of the magnetic shaft between the grooves 20 causes the amplitude in the corresponding pickup coil signal to be relatively large, and the positioning of the non-magnetic grooves 20 adjacent the core 50 results in amplitude reduction. The magnetic material of the edges 38 of the shaft 12a (Figs. 5 and 6) adjacent the core 50 results in signal amplitude increases, while orientation of the flats 30 adjacent the sensor 14 is coincident with increased displacement of magnetic mat rial from the core 50 to cause a reduction in signal amplitude. Finally, the magnetic projections 40 carried by the shaft 12b (Figs. 7 and 8), adjacent the core 50, cause increased signal amplitude at the pickup coils, while rotation of the shaft to remove the projections from the vicinity of the sensor 14 results in reduced signal amplitude at the pickup coils.

The exciter coil 52 is positioned aligned with the cylindrical shaft portion 25 in the two versions of the shaft which include the grooves 20 (Figs. 2, 3 and 3A), including the case of the non-magnetic shaft 12 with the magnetic filler material 29 residing in the grooves and the case of the magnetic shaft 12′ with the empty, or non-magnetic, groov s 20. With the magnetically-filled grooves of the non-magnetic shaft 12 (Figs. 2 and 3), the magnetic material 29 is sufficiently concentrated that the distinction between the closed confuguration, wherein the magnetic material is adjacent the sensor 14, and the open configuration wherein the magnetic material has been rotated out of such configuration, is sufficiently great to provide amplitude modulation of relatively high signal-to-noise ratio.

In the case of the magnetic shaft 12′ and non-magnetic grooves 20 (Figs. 3A), as well as the variation including a magnetic shaft 12a with flats 30 and edges 38 (Figs. 5 and 6), wherein the exciter coil 52 is always facing magnetic material, such as the cylindrical surface 36 in the case of the flats-and edges version, the flux linkage closing when the magnetic material is closest to the sensor 14 is enhanced by the exciter coil being adjacent magnetic material to permit relatively large signal amplitude at the respective pickup coil 54 or 56. If necessary, the distinction between such linkage, in the closed configuration, and the open configuration, wherein the grooves 20 or flats 30 are adjacent the core 50, but with the exciter coil 52 still facing magnetic material in the cylindrical portions 25 (Figs. 2 and 3a) or 36 (Figs. 5 and 6), may be enhanced by providing bevelled field-focusing core legs 57–59 as illustrated in Fig. 10 and discussed hereinbefore.

Although field-focusing core legs may also be employed with the version of the spinner transducer with the shafts 12b carrying projections 40 of magnetic material, the variation in displacement of magnetic material relative to the core 50 as the shaft rotates in that case is sufficiently distinct, and each projection 40 overlaps the exciter coil 52 to enhance the closing of the core 50 between the exciter coil and the respective pickup coil 54 or 56, so that the amplitude modulation of the pickup coil signals may be expected to be of sufficiently large signal-to-noise ratio without the use of such focusing.

Sinc the shaft in each version of the spinner transducer illustrated and described herein carries magnetic material within the general vicinity of the sensor 14, and since the vary-

ing electromagnetic field generated by the exciter coil 52 may be expected to transmit electromagnetic signals to the pickup coils 54 and 56 even in th total absence of such magnetic material carried by the shaft, a flux leakage may be expected, which would tend to provide background signals always present at the pickup coils 54 and 56. Consequently, the electromagnetic signals available at the pickup coils 54 and 56 are sinusoidal carrier waves of non-zero amplitudes, which are modulated by the rotation of a magnetically-coded shaft to produce pulses in the carrier wave amplitudes.

The amplitude modulated output signal of each of the pickup coils 54 and 56 is of the same frequency as the sinusoidal wave impressed on the exciter coil 52 by the oscillator 62 and the driver 64. The specific frequency of the carrier signal provided by the oscillator 62 is not critical, since the information concerning the speed and rotational direction of the shaft is carried by the amplitude modulations of the output signals from the pickup coils 54 and 56, and not by the frequency of the carrier signals so modulated. The pulse rate of each modulated signal from a pickup coil will, at any moment, be equal to the rotational frequency of the shaft multiplied by the number of magnetic keys (grooves, edges projections, etc.) in the corresponding set of coding keys. For example, with a constant shaft rotational speed and four projections 40 in a set 42 or 44 (Figs. 5 and 6), the resulting pulse rate of the amplitude modulated pickup coil signal is four times the shaft rotational frequency.

The amplitude modulated signals provided by the pickup coils 54 and 56, which signals are designated as A and B, respectively, in Figs. 11 and 12, are carried by appropriate conductors 68 and 70, respectively to the pulse counting circuitry 16 illustrated in Fig. 12. The exciter coil input signal C from the driver 64 is also carried to the pulse counting circuitry 16 by appropriate conductors 72. Symbolic representations of the three signals A, B and C are included in the timing chart of Fig. 13, which illustrates relationships among the signals, and their processed versions. Fig. 13 illustrates the case of an upper set of magnetic coding along a shaft, in any version, being offset by one quarter phase to the right relative to the positioning of the lower coded set, as viewed in any of the side elevations herein (Figs. 2, 5 7) for exampl , and with the shaft rotating counter-clockwise, that is, from left to right as viewed in such elevations. Such configuration and direction of rotation is consistent with the fact that the pulses in signal A are illustrated in Fig. 13 as leading the corresponding pulses of signal B by approximately a 90° phase shift. The ovelapping in time of corresponding pulses in the signals A and B in Fig. 13 indicate that the coding keys in the two coding sets carried by the shaft in question are positioned to overlap in their respective rotati nal orientations on the shaft, as, for example, in the case of the grooved version of Fig. 3 or the flats-and-edges version of Figs. 5 and 6. The particular pulse shapes included in signals A and B are determined, at least in part, by the magnetic coding key configurations as well as the rate of rotation of the shaft in question.

Earth of the signals A, B and C is initially processed in a similar manner, and the signals are ultimately compared as described hereinafter. For example, the output signal A from the upper pickup coil 54 is received, by means of the conductors 68, by an amplifier and rectifier circuit 74, which amplifies the signal and converts it to a pulsed dc signal. A filter circuit 76 then limits the frequency of the carrier signal, and intergrates the signal to form a dc signal of square pulses, designated A1 and illustrated in Fig. 13. The voltage of the squared pulse signal A1 is then increased in an amplifier circuit featuring a gain adjustment 78. Typically, an increase of 200 may be utilised, while the gain adjustment may be used to compensate for magnetic flux leakage that occurs at the shaft. Similarly the output signal B from the lower pickup coil 56 is converted to a dc signal of increased amplitude by an amplifier and rectifier circuit 80, and then filtered and integrated by the filter circuit 82 to produce a square pulsed signal B1, as illustrated in Fig. 13. The signal B1 is also increased in voltage by an amplifier circuit featuring a gain adjustment 84 to compensate for flux leakage. Fig. 13 is not drawn to scale to the extent to allow a voltage comparison between the representations of signals A, B, C and signals A1, B1.

The driver circuit output signal C is also converted to a dc signal of increased amplitude by an amplifier and rectifier circuit 86. It should be noted that the carrier signal C is of constant amplitude, so that when the dc version of the driver signal is filtered and integrated by a filter circuit 88, a constant amplitude dc signal C1 is produced, as illustrated in Fig. 13. Subsequently, an amplifier circuit with gain adjustment 90 increases the voltage level of the rectified/integrated driver circuit signal and compensates for flux leakage as in the previously described cases.

The output from the amplifier circuit 90 serves as a reference voltage in two voltage c mparators 92 and 94, which receive the output signals from the pickup coil signal circuit amplifiers 78 and 84, respectively. In each case, the difference between the reference voltage and the amplified, squared pickup coil pulse signal is determined, and where the difference is non-zero a square pulse is generated for the duration of the measured non-zero value. Thus, the output from the comparator circuit 92, which com-

pares the processed signal from the upper pickup coil 54 to the reference voltage, is a squared pulse signal A2 as illustrated in Fig. 13. The corresponding output signal from the comparator circuit 94, which compares the reference voltage to the processed signal from the lower pickup coil 58, is a squared pulse signal B2 as illustrated in Fig. 13.

The difference between the reference voltage and each of the processed pickup coil signals, as compared in the comparator circuits 92 and 94, respectively, reflects the variations in amplitude of the signals in the pickup coils 54–58, compared to the driver signal C impressed on the exciter coil 52, due to shunting of the core 50 by the magnetic keys on the rotating shaft. The two signals A2 and B2 reflect the time relationship between the initial pickup coil signals A and B, but provide specific leading and trailing edges to allow an accurate determination of the direction of rotation of the shaft, and to permit an accurate determination of the period of the pulses in either signal A2 or B2 whereby the rate of rotation of the shaft may be accurately determined. The rate of shaft rotation is determined by the number of square pulses in either of the signals A2 or B2 in a given period of time, divided by the number of magnetic coding keys in the corresponding set of keys on the shaft. The direction of rotation of the shaft, whether clockwise or counter clockwise, is determined by which one of the two pulsed signals A2 or B2 leads the other, as evidenced by the relative positions of the pulses of the signals on the time chart shown in Fig. 13. Setting the phase difference between the signals at 90° assists in this determination. The overlapping of corresponding pulses in the two signals A2 and B2, due to overlapping of corresponding magnetic keys in the two encoded sets on the shaft, also facilitates the determination of which signal leads the other. The scaling of Fig. 13 does not allow comparison of the voltage values of signals A2, B2 with signals A, B C or A1, B1.

The signals A2 and B2 may be compared in a speed and direction determinator circuit 96, which may be of any convenient design. For example, a logic circuit may be utilised for this purpose, readily receiving and processing the square pulses of the signals A2 and B2. The output from the determinator circuit 96 may be of any convenient form, containing either a digital or analog signal with the speed of rotation information in the form of time-coded pulses, for example, and the direction of rotation information in the form of a positive- or negative-going pulse, for example. The determinator circuit output may be displayed by an appropriate readout circuit 98, which may include one or more stripchart recorders, meters, digital outputs or the like. Details of the determinator and readout circuits are not critical to the present invention.

A spinner transducer toll according to the present invention can be utilised in virtually any situation where speed and/or direction of rotation of a body, such as a shaft, is to be determined. Particular details of such an application are not essential to the understanding of the present invention. However, one such application is considered herein for purposes of illustration, and presentation of the present invention within an environment. The fluid flow measuring device 11 incorporating the spinner transducer tool 10 as shown in Figs. 1A–1E is of a type useful in oil well exploration and development activities. The flow measuring device 11, which may be employed with a variety of other well working tools (not shown) is positioned within a well and utilised to determine the rate of flow of fluid, such as water and/or oil, along the w ll bore.

The flow measuring device 11 is generally elongate and constructed with a fluid-tight outer casing assembly shown generally at 100, which may be selectively opened toward the bottom of the measuring device to receive fluid flowing upwardly along a well bore. The fluid flowing into the measuring device activates the spinner transducer tool 10 (Fig. 1D) whereby flow rate and direction measurements are obtained, and then exists the measuring device to continue along the borehole. The casing 100 as well as various internal elements of the flow measuring device 11 are constructed of multiple components mutually attached and fluid-sealed by appropriate seal members, such as O-rings residing in annular grooves, as illustrated throughout Figs. 1A–1D.

In Fig. 1A, the top of the fluid flow measuring device 11 is illustrated as continuing downwardly from other equipment (not shown) by which the flow measuring device may be positioned within a well borehole. An electronics assembly 102 is positioned toward the top of the fluid flow measuring device 11, and includes the exciter circuit 15 and possibly the pulse-counting circuit 16, and also power supply apparatus to support such down-hole circuitry. The electronics assembly 102 may be in communication with equipment at the surface, such as the readout equipment 98 (Fig. 12) and control equipment (not shown), by appropriate connectors (not shown) extending upwardly from the assembly 102. A pair of set screws 104 may be provided to maintain the electronics assembly 102 firmly in place within the casing assembly 100.

A motor housing assembly 106 includes a motor 108 maintained fixed within the housing assembly by set screws 110 and connected by appropriate conductors 112 to the electronics assembly 102 which may also include appropriate power supply components to operate the motor. Th drive shaft of the

motor 108 is joined by a connector assembly 114 to a switch lead screw 116, which features fine, small-pitch threads (Fig. 1B). The lower end of the screw 116 features an upset 118, which may ride against a thrust bearing assembly 120 positioned between the upset and the housing 106, and which upset is circumscribed by a radial bearing assembly 122. The lead screw 116 is thus able to rotate with the drive shaft of the motor 108, and is prevented from exerting upward force against the motor by the thrust bearings 120.

The switch lead screw upset end 118 resides within a drive lead screw housing 124 and is connected to the top end of a drive lead screw 126 by means of a tongue-in-groove connection shown generally at 128. Thus, the drive lead screw 126 is rotatably fixed relative to the switch lead screw 116, both lead screws being selectively rotatable about their respective coincidental longitudinal axes by operation of the motor 108. A double-ring seal assembly shown generally at 130 rotatably seals the drive lead screw 126 to the drive screw housing 124 at the top end of the drive screw. A bearing 132, held in place by an appropriate bolt 134, supports the bottom end of the drive lead screw 126 (Fig. 1C). The bearing bolt 134 may be positioned through an access opening 136 in the drive screw housing 124; an additional access opening 138, which may be closed by a threaded plug, is provided to access the top end of the drive lead screw 126. An access opening 140 is provided in the motor housing 106 at the location of the coupling 114.

Upper and lower limit switches 140 and 142, respectively, are mounted in appropriate recesses in the side of the motor assembly housing 106 toward opposite ends of the threaded portion of the switch lead screw 116. Each limit switch 140 and 142 features a pair of bolt contacts, extending through appropriate bores in the housing 106 to the interior passage 144 containing the switch lead screw 116, the bolt contacts in each case being mutually displaced longitudinally along the passage 144. Each of the switches 140 and 142 is connected to the electronics assembly 102 and/or the motor 108 by appropriate conductors (not shown), and forms a part of the circuitry controlling operation of the motor. A switch follower 146 threadedly engages the switch lead screw 116, and may be held against rotation by an appropriate spline assembly or other connection (not shown) with the lead screw housing 106, for example. Thus, as the motor 108 rotates the switch lead screw 116, the follower 146 moves longitudinally along the threads of the lead screw, upwardly or downwardly depending on the direction of rotation f the screw. Contact of the follower 146 with either of the limit switches 140 or 142 produces appropriate switching in the motor control circuitry to automatically stop rotation of the motor 108 and, therefore, the two lead screws 116 and 126.

The l ad screw housing 124 features an extended recess 148 within which resides coarse, large-pitch threads of the drive lead screw 126 (Fig. 1C). A sleeve assembly 150 generally circumscribes the drive lead screw housing 124, extending downwardly as further described hereinbelow. The sleeve assembly 150 is coupled to the drive lead screw 126 by a follower block 152, fixed to th sleeve assembly by a bolt 154 and threadedly engaging the drive screw. The sleeve assembly 150 is otherwise longitudinally movable relative to the lead screw housing 124. As the drive lead screw 126 is rotated, the coupling therewith of the follower 152 results in longitudinal movement of the sleeve assembly 150 relative to the drive lead screw housing 124, upwardly or downwardly depending on the direction of position of the drive screw. Since the threads of the drive lead screw 126 and of the follower 152 are of large pitch compared to the threads of the switch lead screw 116 and the switch follower 116, the full extent of rotational movement permitted by longitudinal movement of th switch follower 146 between the limit switches 140 and 142 is accompanied by the greater longitudinal movement of the follow r block 152 and the attached sleeve assembly 150 along the threaded portion of the drive lead screw 126. Friction between the sleeve assembly 150 and the screw housing 124 as well as other components described hereinafter prevents rotation of the sleeve assembly and the follower block 152 with the drive screw 126 to cause longitudinal movement of the sleeve assembly as the drive screw is rotated. Alternatively, a spline-type connection could be provided for this purpose.

An impeller housing 156 is mounted on the lower end of the drive lead screw housing 124, and held fixed thereto by at least one bolt 158 (Fig. 1D). The upper portion of the impeller housing 156 is generally tubular, containing a longitudinally-extending passage 160. The impeller housing 156 continues downwardly beyond its cylindrical portion in a multiplicity of arms 162 which support a rod extension 164 ending in a cap, or foot 166 (Fig. 1E).

A plurality of flexible metal strips 168 is mounted and held by appropriate bolts 170, in a circumferential array about the bottom of the cylindrical portion of the impeller housing 156. The bottom ends of the strips 168 are similarly mounted on a generally tubular block 172 by bolts 174. The block 172 circumscribes the rod 164 and is held against rotation relative thereto by a pin 176 mounted in an appropriate bore through the block and riding in a longitudinally-ext nding groove 178 in the r d. A coil spring 180 is com-

pressed between the bottom of the block 172 and the top of the foot 166, and urges the block upwardly relative to the rod 164. Such upward movement of the block 172 tends to longitudinally compress the plurality of strips 168, thereby flexing the strips radially outwardly into the bowed configuration illustrated in Fig. 1E.

The upper halves of the strips 168 are connected by a flexible cloth-like material 182 so that, in the bowed configuration of the combination strips 168 and material 182 as illustrated in Fig. 1E, a funnel or basket assembly is provided, and is indicated generally at 184. Fluid flowing upwardly relative to the basket 184 is directed thereby through the openings between the arms 162 and into the passage 160 of the impeller housing 156. The impeller housing 156 is equipped with ports 185 which are aligned with ports 186 in the sleeve assembly 150 when the sleeve assembly is in the upward configuration as illustrated. Fluid flowing into the bottom of the passage 160 may thus emerge through the ports 185 and 186 to the exterior of the flow measuring device 11.

Rotation of the drive lead screw 126 may be effected by operation of the motor 108 to lower the follower block 152 and, therefore, the sleeve assembly 150 relative to the drive screw and the impeller housing 156. The bottom of the sleeve assembly features a counterbore 150a which facilitates movement of the sleeve assembly down over the extended strips 168. Such enclosure of the strips 168 by the sleeve assembly 150 being lowered relative thereto collapses the basket 184 inwardly toward the rod 164. The collapse of the basket 184 forces the block 172 downwardly, compressing the spring 180 against the foot 166. The motor 108 may be operated until the switch follower 146 reaches the lower limit switch 142, at which time the sleeve assembly follower block 152 will be at the vicinity of the bottom end of the threads of the drive lead screw 126. At that point, the bottom of the sleeve assembly 150 will be positioned essentially adjacent the block 172, fully enclosing the basket 184 minimizing any possible fluid flow into the bottom of the passage 160 through the impeller housing 156. The sleeve assembly ports 186 are longitudinally displaced from the impeller housing ports 185 with the sleeve assembly 150 in its lowered configuration enclosing the collapsed basket 184, further inhibiting fluid movement through the passage 160.

In the closed-basket configuration with the sleeve assembly 150 in its lower position, the flow measuring device 11 may be manipulated within a well with a minimum of resistance to such motion, for example. When the flow measuring device is positioned at th location at which flow measurements ar to be secured, the motor 108 may be operated to rotate the switch lead screw 116 and the drive lead screw 126, raising the sleeve assembly 150 until the switch follower 146 contacts th upper limit switch 140. At that point, the basket 184 will be uncovered and extended by operation of the spring 180 as illustrated in Fig. 1E, and the sleeve assembly ports 186 will be aligned with the impeller housing ports 185 to permit fluid flow outwardly from the casing assembly 100.

The impeller housing 156 contains an impeller assembly shown generally at 187 in Fig. 10, and which comprises the shaft 12 of the spinner transducer tool 10 and one or more impeller blades 188 arranged in spiral fashion on the shaft. It will be appreciated that, while the spinner transducer tool embodiment illustrated in Figs. 2 and 3 is also shown in Fig. 1D, any version of the spinner transducer tool previously described herein may be utilised in the flow measuring devic 11 as illustrated in Figs. 1A–1E. The shaft 12 is mounted between an upper, fixed bearing 189 positioned within a counterbore in the drive lead screw housing 124, and a lower, adjustable threaded pin bearing 190, which is threadedly engaged in a mounting frame 192 held fixed by appropriate means within the passage 160 of the impeller housing 156. A friction clamp 194 maintains the pin bearing 190 in its selected position with its point against the generally flat bottom of the shaft 12, while the pointed top end of the shaft rides in a recess in the bottom of the upper bearing 189. The bearing frame 192 includes multiple passages 196 for fluid flow along the impeller housing passage 160. The impeller assembly 187 is thus free to rotate about its longitudinal axis, riding on the upper and lower bearings 189 and 190, respectively. The spiral configuration of the impeller blades 188 permits the passage of fluid flowing upwardly within the impeller housing passage 160 and out through the aligned ports 185 and 186 with such rotation about the shaft access.

It will be appreciated that the rate of rotation of the shaft 12, caused by fluid flowing along the passage 160 and impacting on the impeller blades 188, is directly proportional to the rate of fluid flow along the passage. The direction of rotation of the shaft 12 is also determined by the relative direction of flow of the fluid in the passage 160 with respect to the impeller assembly 185. While the spinner transducer tool 10, even as incorporated in the flow measuring device 11, may, in general, detect the direction and rate of flow of fluid in either longitudinal sense along a direction parallel to the axis of the shaft 12, the flow measuring device illustrated in Figs. 1A–1E is particularly designed to sense flow rate for fluid moving upwardly relativ to th device, having entered the extended basket assembly 184, moving along the impeller

housing passage 160 and exiting the flow measuring device casing assembly 100 through the aligned ports 185 and 186.

With fluid flowing upwardly through the passage 160 and by the impeller assembly 187 as described, the sensor 14 detects the passage of the magnetic keys on the shafts 12 as discussed hereinbefore, and communicates the data signals to the electronic assembly 102 for processing. The detector mechanism 14 is positioned within a recess 197 in the drive screw housing 124, and separated by the wall 60 from a longitudinal recess 198 which encompasses a portion of the shaft 12, including the magnetic key sections 22 and 24. The bearing 189 is mounted in a counterbore at the end of the recess 198.

The detector mechanism may be secured, e.g. by an epoxy resin adhesive (not shown), in position within the recess 197, or held in place by any appropriate means. An extended passage 200 is provided along the drive screw housing 124 from the recess 197 to the top of the housing (Fig. 1D) to accommodate appropriate conductors (not included for purposes of clarity) communicating between the detector mechanism and the electronic assembly 102. Sufficient space accommodates such conductors along the annular region between the motor housing assembly 106 and a casing member 202, which circumscribes a large portion of the motor housing assembly 106, being sealed thereto, and which is sealed to the top of the drive lead screw housing 124 (Fig. 1B). an elongate port 204 permits the conductors to pass to the interior of the motor housing assembly 106 above the motor assembly 108 for connection to the electronics assembly 102 (figure 1A). The conductor communication passage 200 may be constructed, in part, by covering a trough, cut in the side of the drive lead screw housing 124, by a strip 205, shown welded in place in Fig. 1C.

A pair of double-ring seal assemblies shown generally at 206 and at 208 seal the exterior of the drive lead screw housing 124 to the top of the impeller housing 156, the latter having fluid flowing within its interior through the passage 160. As shown in Figs. 1C and 1D, the impeller housing passage communicates through the recess 198, around the impeller bearing 189 (which is not sealed to the drive screw housing 124) and through to the recess 148 by means of a narrow passage opening into the recess containing the driv screw bearing 132. Fluid pressure communication between the passage 160 and the recess 148 along this interior path avoids pressure or vacuum locks in the raising and lowering of the sleeve assembly 150.

Once the operation of measuring fluid flow rate within a well by use of the spinner transducer 10 as mounted within the flow measuring device 11 of Figs. 1A–1E is completed, the motor may be selectively operated from the surface to lower sleeve assembly 150 ov r the basket assembly 184, rendering the flow measuring device in its collapsed configuration as was utilized for insertion and positioning within the well. The flow measuring device 11 may then be further manipulated within the well, or removed therefrom.

The spinner transducer tool, in any of its embodiments described herein, provides an accurate tool for measuring speed and direction of flow of fluid, for example. The use of alternating magnetic fields and reliance on amplitude modulation as opposed to frequency modulation of the data signal enables reliable and accurate measurements to be made that are impervious to vibration of the impeller shaft. Further, the spinner transducer tool of the present invention includes virtually no magnetic drag on the impeller shaft, due to the fact that the magnetic fields involved are alternating, and further provides accurate and reliable measurements for slow rotational speed approaching zero rate of rotation. Also, the high temperature rating of the ferrite core of the detector mechanism 14 is particularly suitable for use in high temperature environments, such as may be encountered in wells. The thin wall separation of the detecter mechanism from the impeller shaft completely isolates the detector from the fluid-filled environment in the shaft.

While the present invention has been shown in the environment of a fluid flow measuring device finding particular use in wells, the spinner transducer tool is not limited to such applications, but may rather be employed in any operation which requires the measurement of the speed and/or of rotation of a shaft, whether caused by fluid flow or otherwise.

CLAIMS

1. Apparatus for sensing motion of a body, said apparatus comprising:

a detector including a primary coil for generating an electromagnetic field signal and a secondary coil positioned to pick up said signal and provide an output signal representative thereof;

encoding means, including magnetic material, associated with said body for movement therewith; and

said detector being disposed adjacent said body so that movements f the body moves the encoding means relative to the detector to vary the degree of flux linkage provided by said magnetic material between the primary coil and the secondary coil, whereby to vary the magnitude of said output signal in respons to said motion.

2. Apparatus according to claim 1 wherein said encoding means comprises first and second mutually displaced sets of zones, each set

including at least two zones of differing magnetic effect, wherein first and s cond said secondary coils are disposed on opposite sides of said primary coil, and wherein said detector is disposed so that movement of the body moves the first zone set adjacent the first secondary coil and moves the second zone set adjacent the secondary coil, whereby to provide varying output signals from each of said secondary coils.

3. Apparatus according to claim 2 wherein said encoding means is provided on a shaft whose rotary motion is tio be sensed, said two sets being displaced longitudinally of said shaft.

4. Apparatus according to claim 3 wherein the zones in the second set are offset cirumferentially relative to the zones in the first set, whereby the variations in the output signals from the first and second secondary coils have a phase difference therebetween representative of the sense of rotation of the shaft.

5. Apparatus according to any one of claims 1 to 4 including means for applying an alternating current to said primary coil to generate an alternating said electromagnetic field signal, whereby said output signal comprises an alternating current which is amplitude modulated in response to said motion to permit determination of the speed of said motion.

6. Apparatus according to any one of claims 1 to 5 wherein said encoding means is provided by said body being formed mainly of material of relatively low magnetic permeability with predetermined zones of material of relatively high permeability located therein.

7. Apparatus according to any one of claims 1 to 5 wherein said encoding means is provided by spatial variations in the shape of said body to vary the spacing between the magnetic material of said encoding means and said detector in response to said motion.

8. Apparatus according to any one of claims 1 to 5 wherein said encoding means is provided by said body being formed at least in part of magnetic material with at least one recess opening onto the surface of the body.

9. Apparatus according to any one of claims 1 to 5 wherein said encoding means is provided on a shaft whose rotary motion is to be sensed, said encoding means being provided by a circumferential array of longitudinally extending shaft portions having edges of said magnetic material.

10. Apparatus according to any one of claims 1 to 5 wherein said encoding means is provided on a shaft whose rotary motion is to be sensed, said encoding means being provided by at least one radial projection of said magnetic material from the shaft.

11. Apparatus according to any one of claims 1 to 10 wh rein said detector comprises a core of solid f rrite material carrying said primary and secondary coils.

12. Apparatus according to claim 1 wherein said detector is adapted to provide two said output signals out of phase with one another to permit determination of both the speed and sense of said motion.

13. Apparatus for sensing the rotary motion of a shaft, said apparatus comprising:

a detector including a primary coil for generating an alternating electromagnetic field signal and a secondary coil positioned to pick up said signal and provide an alternating output signal representative thereof;

encoding means, including magnetic material associated with said shaft for rotation therewith;

said detector being disposed adjacent said shaft so that rotation of the shaft rotates the encoding means relative to the detector to vary the degree of flux linkage provided by said magnetic material between the primary coil and the secondary coil, whereby to modulate the amplitude of said alternating output signal in accordance with the speed of rotation of the shaft.

14. Apparatus according to claim 13 wherein said detector includes first and second secondary coils disposed so that the amplitude modulation of the output signal from the second secondary coil is out of phase with the amplitude modulation of the output signal from the first secondary coil, to permit determination of both the speed and sense of said rotation of said shaft.

15. Apparatus according to claim 14 wherein said first and second said secondary coils are disposed on opposite sides of said primary coil, wherein said encoding means comprises first and second sets of magnetic keys mutually displaced longitudinally along said shaft, and wherein said detector is disposed so that rotation of the shaft rotates the first key set past the first secondary coil and the second key set past the second coil.

16. Apparatus according to claim 15 wherein said first key set is offset circumferentially relative to the second key set.

17. Equipment for sensing the rate of flow of a fluid through a conduit, said equipment including apparatus as claimed in any one of claims 13 to 16 and an impeller connected to said shaft, said impeller being adapted to be driven by said fluid flow to rotate said shaft in accordance with the rate of flow of said fluid.

18. Apparatus for sensing motion of a body substantially as described herein with reference to the accompanying drawings.

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